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# Supersymmetric Model of Radiative Seesaw Majorana Neutrino Masses

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**Abstract**

The radiative seesaw mechanism proposed recently is minimally extended to include supersymmetry in a specific model. Relevant related issues such as leptogenesis and dark matter are discussed.

If the standard model (SM) of particle interactions is extended to include three heavy neutral singlet Majorana fermions $N_i$ ($i = 1, 2, 3$) and a second scalar doublet $\eta = (\eta^+, \eta^0)$ with zero vacuum expectation value (VEV), together with an exactly conserved discrete $Z_2$ symmetry under which $N_i$ and $\eta$ are odd and all SM particles are even, then a radiative seesaw mechanism is obtained [1, 2, 3] for small Majorana neutrino masses. The key is a quartic scalar term

$$\lambda_5 (\Phi^\dagger \eta)^2 + H.c., \tag{1}$$

where $\Phi = (\phi^+, \phi^0)$ is the SM Higgs doublet, which is allowed under $Z_2$. However, such a term is not available in a supersymmetric context. Hence a supersymmetric version of this mechanism is not so straightforward. Nevertheless, it may be accomplished in a minmal extension, as shown below.

Table 1: Particle content of proposed model.

| Superfield | $SU(2) \times U(1)$ | $Z_2$ | $Z_2'$ |
|---|---|---|---|
| $L_i = (\nu_i, l_i)$ | $(2, -1/2)$ | $-$ | $+$ |
| $l_i^c$ | $(1, 1)$ | $-$ | $+$ |
| $\Phi_1 = (\phi_1^0, \phi_1^-)$ | $(2, -1/2)$ | $+$ | $+$ |
| $\Phi_2 = (\phi_2^+, \phi_2^0)$ | $(2, 1/2)$ | $+$ | $+$ |
| $N_i$ | $(1, 0)$ | $-$ | $-$ |
| $\eta_1 = (\eta_1^0, \eta_1^-)$ | $(2, -1/2)$ | $+$ | $-$ |
| $\eta_2 = (\eta_2^+, \eta_2^0)$ | $(2, 1/2)$ | $+$ | $-$ |
| $\chi$ | $(1, 0)$ | $+$ | $-$ |

Consider the superfields listed in Table 1. Whereas $L_i$, $l_i^c$ ($i = 1, 2, 3$) are the usual lepton superfields of the minimal supersymmetric standard model (MSSM) and $\Phi_{1,2}$ the usual Higgs superfields, $N_i$ are new Majorana lepton superfields, $\eta_{1,2}$ and $\chi$ are new scalar doublet and singlet superfields respectively. The $Z_2 \times Z_2'$ discrete symmetry serves to distinguish the three different kinds of doublets $L_i$, $\Phi_1$, and $\eta_1$, as well as the two different kinds of singlets

$N_i$ and $\chi$. Consequently, the superpotential of this model is restricted to be of the form

$$\begin{aligned} W &= f_{ij} L_i l^c_j \Phi_1 + h_{ij} L_i N_j \eta_2 + \lambda_1 \Phi_1 \eta_2 \chi + \lambda_2 \Phi_2 \eta_1 \chi \\ &+ \mu_\phi \Phi_1 \Phi_2 + \mu_\eta \eta_1 \eta_2 + \frac{1}{2} \mu_\chi \chi \chi + \frac{1}{2} M_{ij} N_i N_j. \end{aligned} \tag{2}$$

Since $\eta_2^0$ has zero VEV, $N_j$ are not the Dirac mass partners of $\nu_i$ and the canonical seesaw mechanism [4] is not operative. However, the Yukawa couplings $h_{ij}$ are available and radiative neutrino masses are obtained [1] with the help of $\chi$, as shown in Figure 1.

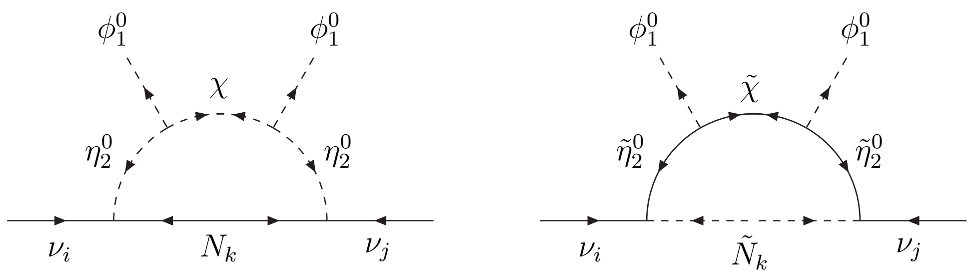


Figure 1: One-loop radiative contributions to neutrino mass.

There are two important consequences of this supersymmetric radiative seesaw mechanism. One is leptogenesis [5]. The decay of the lightest $N_i$ into $L\eta_2$ and their antiparticles will generate a lepton asymmetry which gets converted into the observed baryon asymmetry of the Universe through sphalerons at the electroweak phase transition [6]. On the other hand, the formula for neutrino mass is suppressed by at least a loop factor of $16\pi^2$ as compared to that of the canonical seesaw. This means that the Davidson-Ibarra bound [7] on leptogenesis is reduced by at least two orders of magnitude and the lightest $N_i$ needs to be no heavier than about $10^7$ GeV, allowing it to be comfortably below a possible gravitino bound from the reheating of the Universe after inflation [8].

The other is dark matter [9]. As in the MSSM, $R-$parity is conserved in this model. The lightest particle with $R = -1$ is stable and a candidate for the dark matter of the Universe. Similarly, the lightest particle odd under $Z_2'$ is also stable. In fact, consider the three lightest particles with $(R, Z_2') = (-,+)$, $(+,-)$, and $(-,-)$ respectively. If one is heavier than the other two combined, then the latter are the two components of dark matter. If not, then all three contribute. In other words, dark matter may not be as boring as usually assumed. It may consist of a rich variety of different stable particles.

Except for $N_i$, the new particles of this model, i.e. $\eta_{1,2}$ and $\chi$, are expected to be at the TeV scale and should be observable at the forthcoming Large Hadron Collider (LHC).

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